DOE Solar Energy Technologies Program Peer Review

Technical Track: Nano & Quantum Dots

Project Name: Culn(Ga)Se_2 (CIGS) Nanowire Solar Cells

Principal Investigator: Yi Cui

Denver, Colorado

March 9-10, 2009

Team qualification

Our team consists of excellent members with different expertise. Cui has expertise in nan synthesis, structure and electrical measurement. Noufi is an well-know figure in thin film s cell fabrication, characterization and testing. Zhang is an expert in TEM.

1) PI: Yi Cui, Assistant Professor, Stanford Materials Science.
- King Abdullah University of Science and Technology (KAUST) Investigator Award (Twelve scientists selected)
- ONR Young Investigator Award
- Chaired a Nanowire Symposium in 2008 fall MRS meeting.

2) Students:
- Hailin Peng (postdoc): will start his associate professor position at Peking University i
- David Schoen (Ph.D student): NDSEG and NSF Fellow.
- Jia Zhu (Ph.D student).
- Sang Moo Jeong (Ph.D student): KFAS Fellow.

3) Collaborators:
- Dr. Rommel Noufi (NREL), Consulting Professor at Stanford Materials Science.
- Dr. Xiao Feng Zhang (Hitachi).

Quality, Productivity, Accomplishment

Major accomplishments

- Synthesized successfully and charaterize a family of Cu-In-Ga-Se nanowire materials, including GaSe, In_2Se_3, $In_{2-x}Ga_xSe_3$, $CuInSe_2$.
-Understood the structure evolution during $CuInSe_2$-CdS junction formation.
- In-situ TEM electrical device for direct correlation of structure with property.
- Developed a facile new method in forming single crystalline $CuInSe_2$ nanowires by using In_2Se_3 nanowires as template.

Planned accomplishments

- Synthesize and characterize $CuInGaSe_2$ nanowire materials.
- Perform single nanowire solar cell study.

Facility built

- Nanowire synthesis setup
- Solar simulator and optics system for solar cell measurements.
- Measurement electronics for single nanowire measurements.
- In-situ TEM electrical holder.

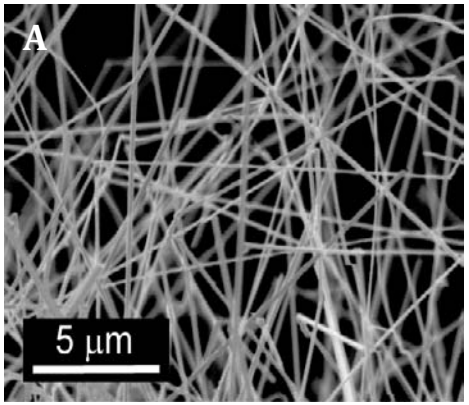
Quality, Productivity, Accomplishment

Our publications).

1) H. Peng, C. Xie, D. T. Schoen, Y. Cui “Large Anisotropy of Electrical Properties in Layer-Structured In_2Se_3 Nanowires” Nano Lett. 8, 1511-1516 (2008).
2) C.-M. Hsu, S. T. Connor, M. Tang, Y. Cui “Wafer-Scale Silicon Nanopillars and Nanocones by Langmuir-Blodgett Assembly and Etching” Appl. Phy. Lett. 93, 133109 (2008).
3) H. Peng, X. F. Zhang, R. D. Twesten, Y. Cui “ Vacancy Ordering and Lithium Ion Insertion in In_2Se_3 Nanowires” Nanoscale Research (in press).
4) D. T. Schoen, H. Peng, Y. Cui “Anisotropy of Chemical Transformation of In_2Se_3 to $CuInSe_2$ Nanowires through Solid State Reaction” J. Am. Chem. Soc. (submitted).
5) H. Peng, S. Meister, C. K. Chan, X. F. Zhang, and Y. Cui “Morphology Control of Layer-Structured Gallium Selenide Nanowires” Nano Lett. 7, 199-203 (2007).
6) H. Peng, D. T. Schoen, S. Meister, X. F. Zhang, and Y. Cui “Synthesis and Phase Transformation of In_2Se_3 and $CuInSe_2$
Nanowires” J. Am. Chem. Soc. 129, 34-35 (2007).
7) H. Peng, C. Xie, D. T. Schoen, K. McIlwrath, X. F. Zhang, Y. Cui "Order Vacancy Compounds and Nanotube Formation
in $CuInSe_2$-CdS Core-Shell Nanowires" Nano Lett. 7, 3734-3738 (2007).

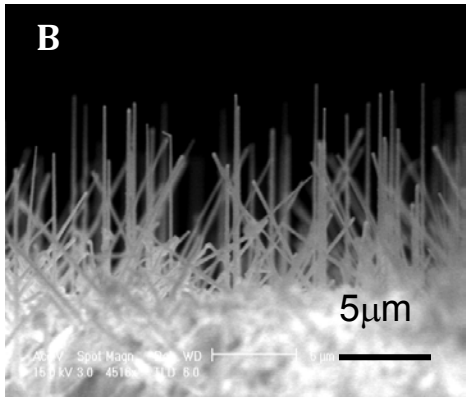
Highlight of achievement 1: synthesis of nanowires

In_2Se_3



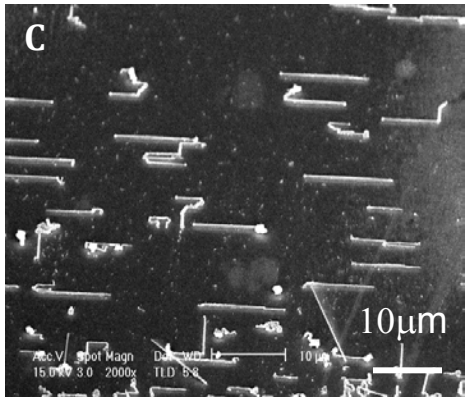
GaSe

In_2Se_3 on GaAs

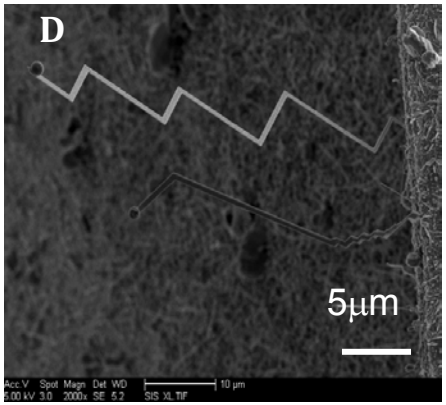


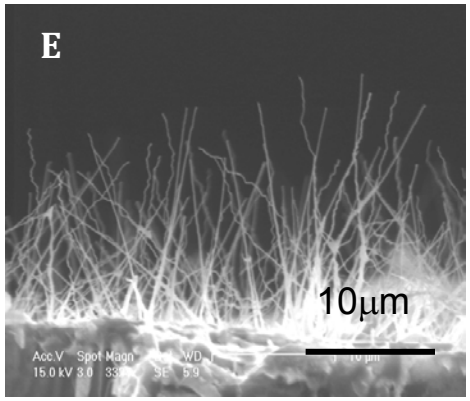
$In_{2-x}Ga_xSe_3$

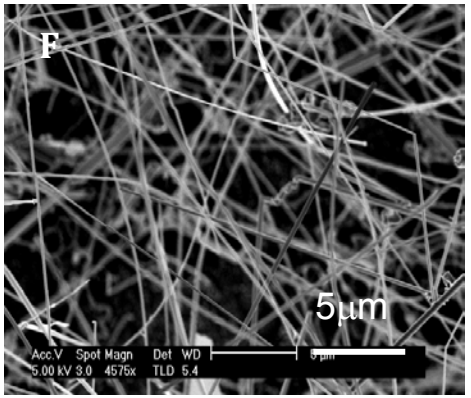
In_2Se_3 on GaAs



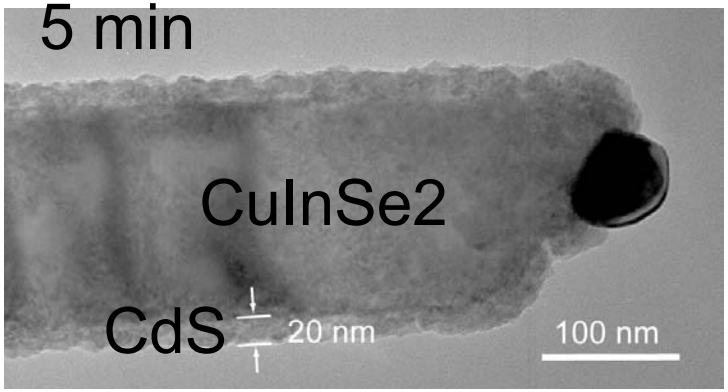
$CuInSe_2$



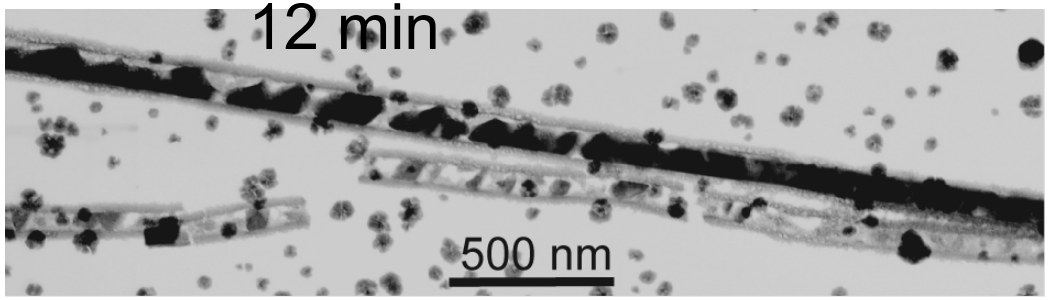


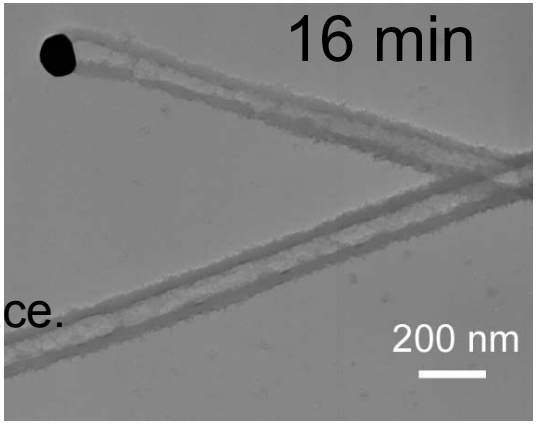


Highlight of achievement 2: structure and property correlatio



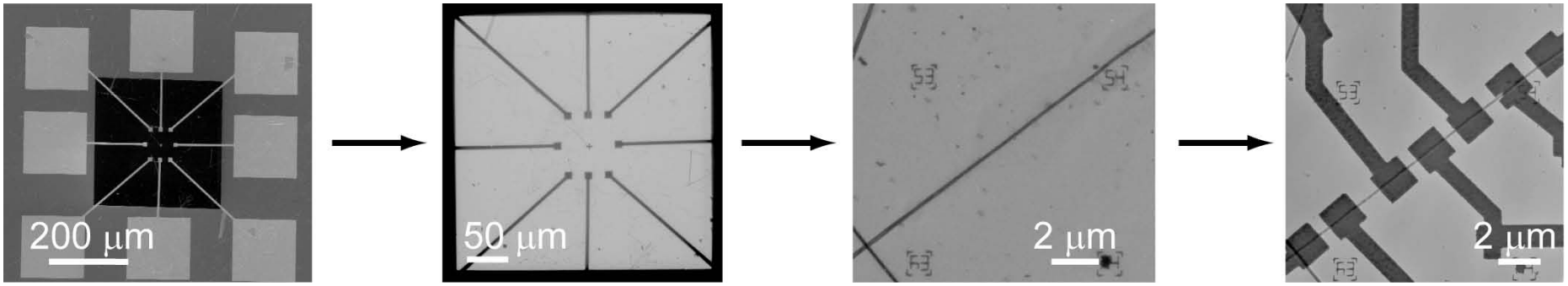
Chemical bath deposition process

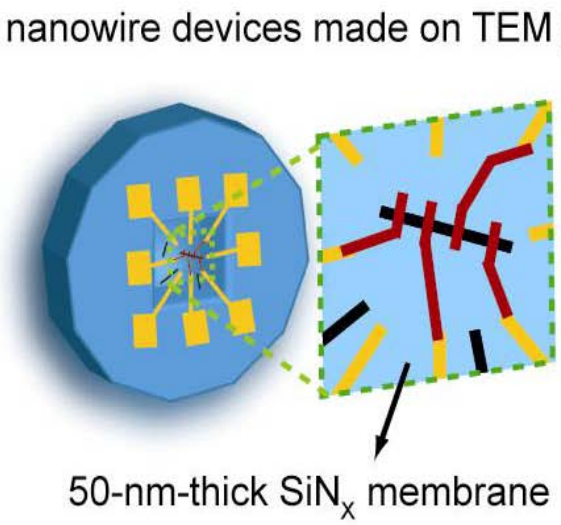


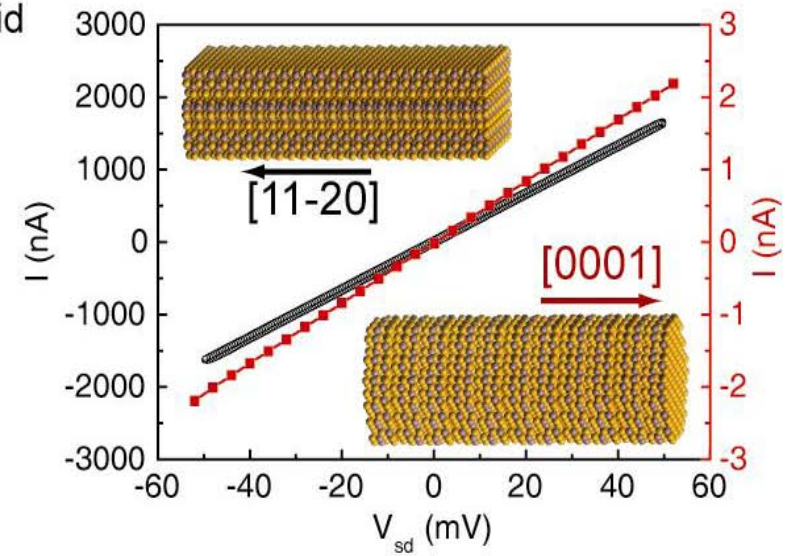


- Cu(I) ions diffuse quickly during CBD process.
- Order vacancy compounds form at the CIS-CdS interface.
- Kirkendal effect was discover during CBD.

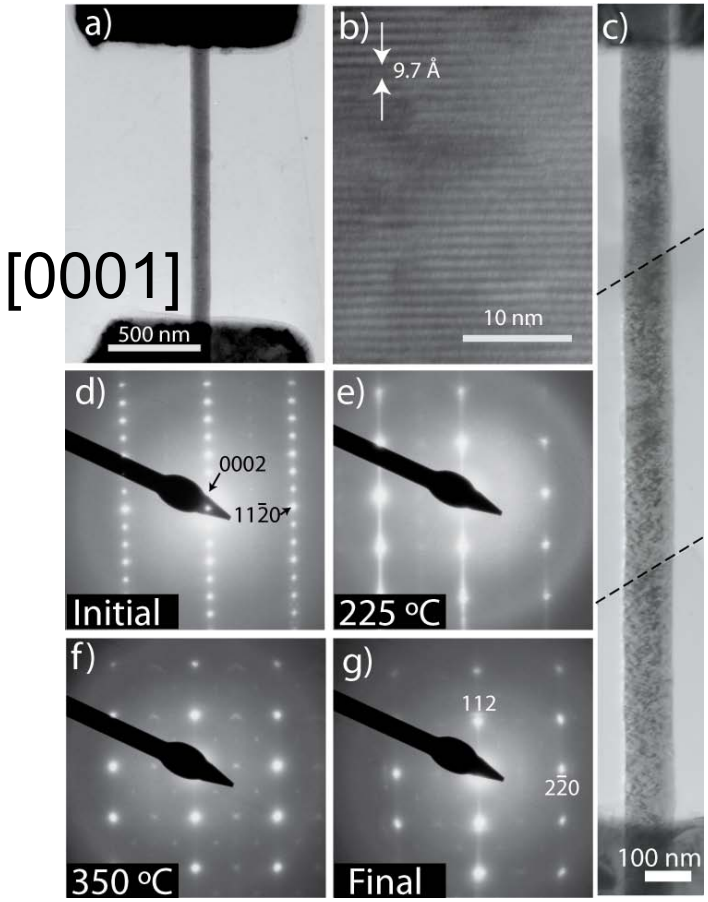
Highlight of achievement 3: in-situ TEM devices for direct structure and property correlation.

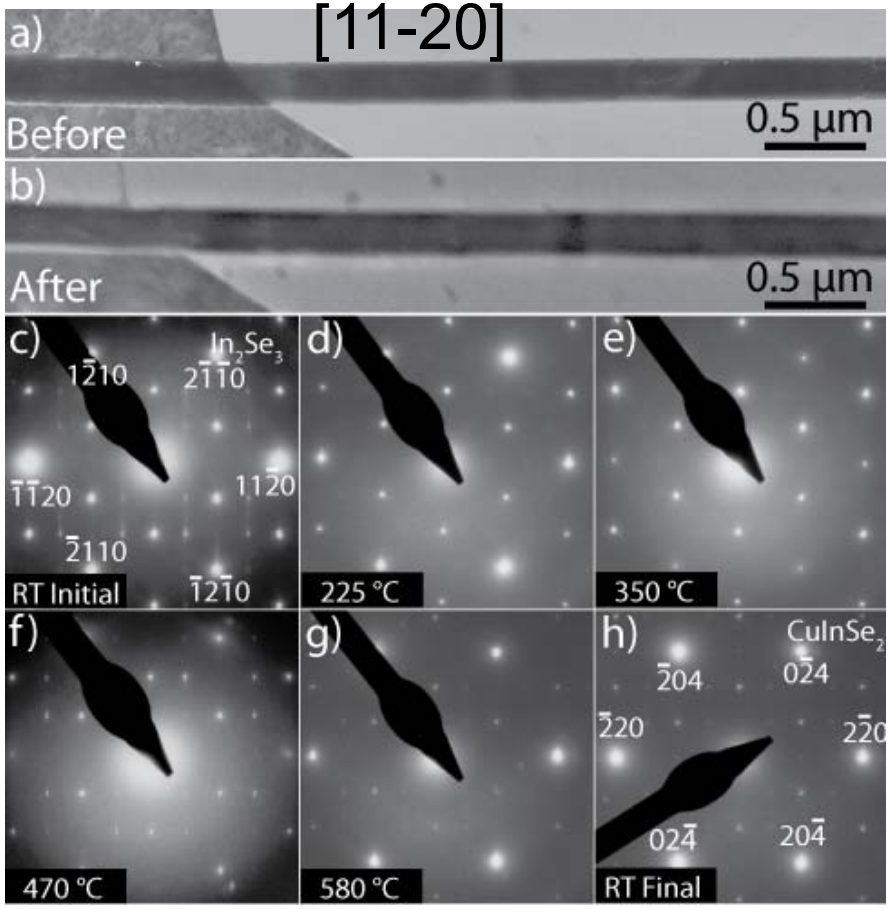






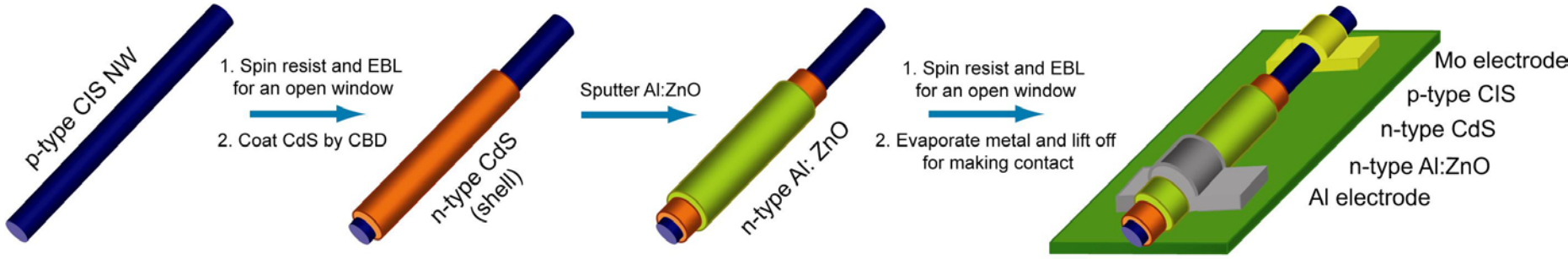
Highlight of achievement 4: solid state conversion of nanowir





- CIS nanowires can be formed by chemically converting In2Se3 nanowires.
- Large anisotropy of chemical conversion is discovered.
- The [0001] In2Se3 nanowires have very low conversion temperature.

Preliminary data on single nanowire solar cells

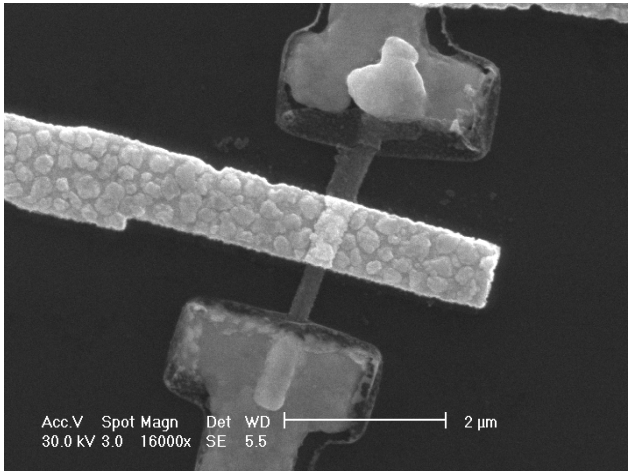


CIS NW made by VLS growth or Cu diffusion

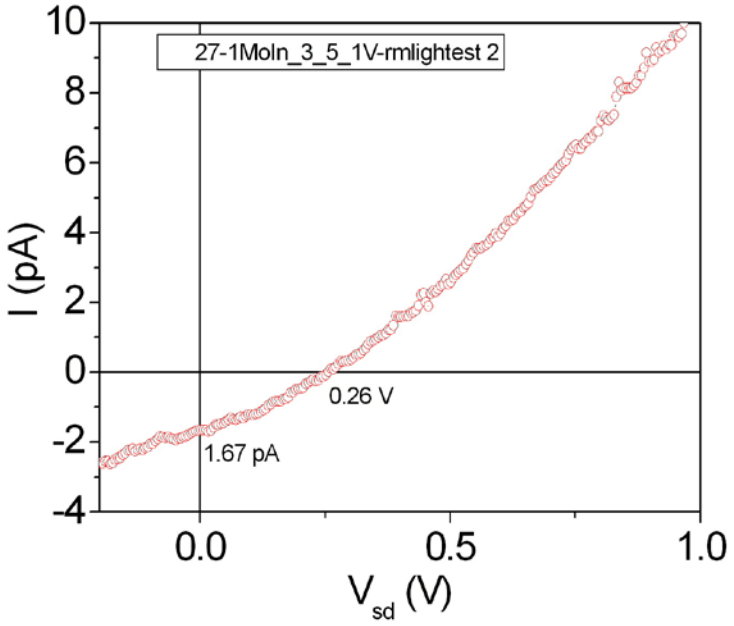
CdS CBD for CIS/CdS core/shell NW

Al:ZnO sputtering

CIS/CdS/Al:ZnO core/multishell NW device fabrication



First single NW solar cell I-V in the sun



Budget and expense

	2008 Budget	Expense and committed	Balance
DOE	$300k	$240k	$60k
Stanford cost-share	$75k	$31k	$44k

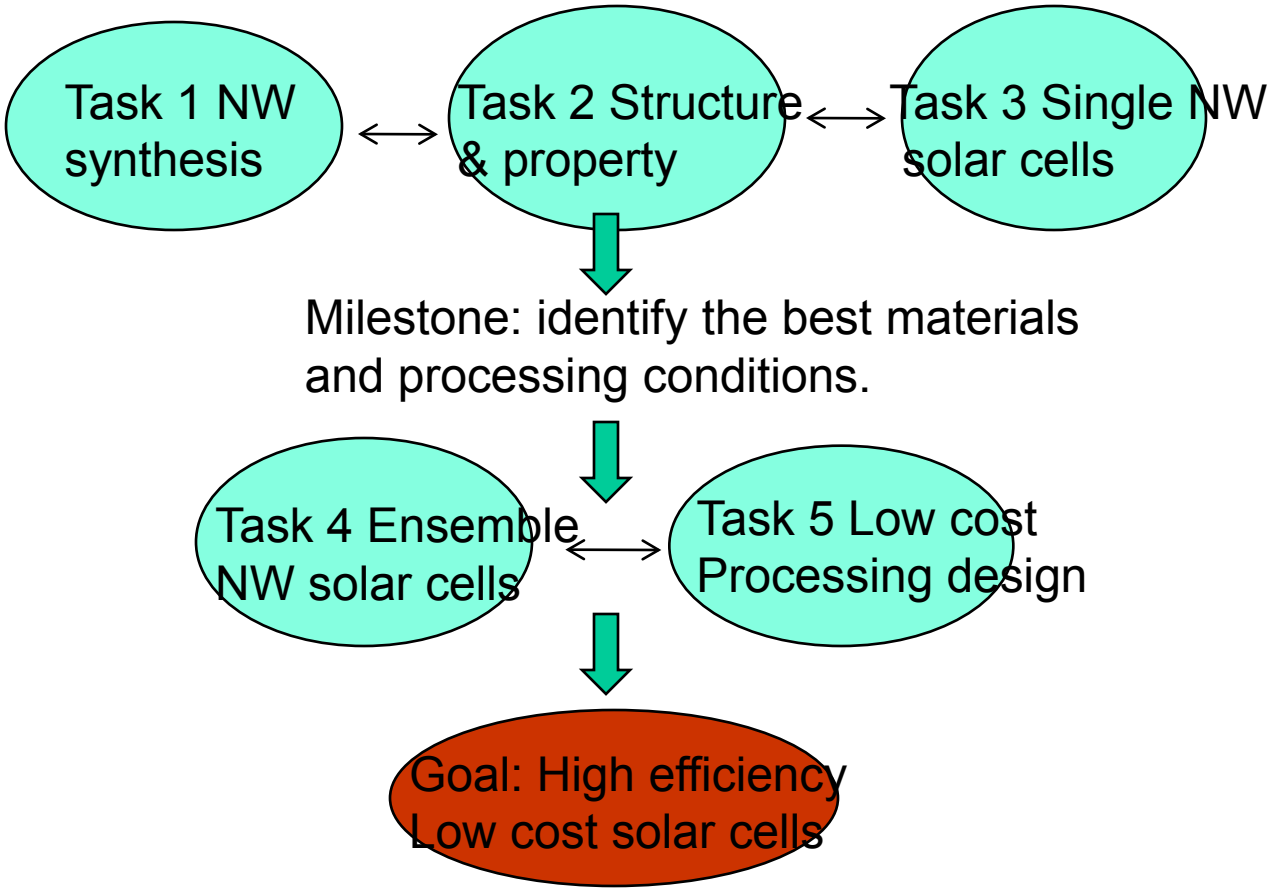
- One postdoc and and one Ph.D student are directly supported by the DOE's funding, which has resulted in our fast progress and good accomplishments.
- The funding came into Stanford in May 2008, which was later than planned. So there is a remaining balance. One more researcher will be hired to increase the productivity.

Scientific/Technical Approach

Goal: High efficiency and low cost solar cells.

- Develop nanowires of CIGS materials family for better correlation of structure and prope
- Identify the best materials, device structure and processing for solar cells.
- Develop low-cost and environment-friendly materials and processes.

Approach:



Relevance/Impact of Research

- The direct correlation of nanowire structure with property and solar cell performance at the single nanowire device level allows us to indentify the best materials and processing resulting in high efficiency solar cells.
- This project will also develop the low-cost and better controlled process for CIGS family of materials.
- The results in this project not only benefit nanowire-based solar cells but also provide important fundamental insights on traditional thin film CIGS solar cell device and processing, which will benefit the applications already in the market.

Future Directions

- Perform carefully single nanowire solar cell studies.
- Design device structure for ensemble nanowire solar cells.
- Develop low-cost processing for solar cell fabrications.